ORIGINAL

Application Based on

Docket **86704NAB**
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APPARATUS AND METHOD FOR CONTROLLED MOVEMENT OF PIXEL IMAGING DEVICE

Commissioner for Patents,
ATTN: MAIL STOP PATENT APPLICATION
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Express Mail Label No.: EV 293537554 US

Date: July 16, 2003

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16 July 2003 10:37 AM

APPARATUS AND METHOD FOR CONTROLLED MOVEMENT OF PIXEL IMAGING DEVICE

FIELD OF THE INVENTION

This invention generally relates to digital electronic imaging apparatus and more particularly relates to an apparatus and method for providing precise movement of an imaging component in orthogonal directions within a fixed plane.

BACKGROUND OF THE INVENTION

The resolution of a two-dimensional digital imaging device is constrained to a given pixel size. In a sensing device, such as a CCD sensor, pixels within the pixel matrix have a fixed size and spacing for detection of an image at a given resolution. Similarly, in a light modulation device, such as a reflective LCD spatial light modulator, pixel size and the spacing of pixels within a two-dimensional array is fixed, constraining the available resolution for forming an image.

Originally developed for forming images in display devices, spatial light modulators are increasingly being used in digital printing applications as well. In printing apparatus, spatial light modulators provide significant advantages in cost and performance over earlier digital imaging technologies, both for line printing systems such as the printer depicted in U.S. Patent No. 5,521,748, and for area printing systems such as the system described in U.S. Patent No. 5,652,661.

Two-dimensional area spatial light modulators, such as those using a digital micromirror device (DMD) from Texas Instruments, Dallas, Texas, or using a liquid crystal device (LCD) can be used to modulate an incoming optical beam for imaging at a given resolution. An area spatial light modulator can be considered essentially as a two-dimensional array of light-valve elements, each element corresponding to an image pixel. Each array element is separately addressable and digitally controlled to modulate light by transmitting (or by blocking transmission of) incident light from a light source, typically by affecting the polarization state of the light.

There are two basic types of area spatial light modulators in current use. The first type developed was the transmissive spatial light modulator, which, as its name implies, operates by selective transmission of an optical beam through individual array elements. The second type, a later development, is a reflective spatial light modulator. As its name implies, the reflective spatial light modulator, operates by selective reflection of an optical beam through individual array elements. A suitable example of an LCD reflective area spatial light modulator relevant to this application utilizes an integrated CMOS backplane, allowing a small footprint and improved uniformity characteristics.

Conventionally, LCD area spatial light modulators have been developed and employed for digital projection systems for image display, such as is disclosed in U.S. Patent No. 5,325,137 and in miniaturized image display apparatus suitable for mounting within a helmet or supported by eyeglasses, as is disclosed in U.S. Patent No. 5,808,800. LCD projector and display designs in use typically employ one or more area spatial light modulators, such as using one for each of the primary colors, as is disclosed in U.S. Patent No. 5,743,610.

Spatial light modulators have also been employed in printing apparatus for photosensitive media. Examples of printing apparatus using digital micromirror devices (DMDs), include that disclosed in U.S. Patent No. 5,461,411. Photographic printers using the more readily available LCD technology are described in U.S. Patent Nos. 5,652,661; 5,701,185; and 5,745,156, for example.

It is instructive to note that imaging requirements for projector and display use (as is typified in U.S. Patent Nos. 5,325,137; 5,808,800; and 5,743,610) differ significantly from imaging requirements for printing by photoprocessing apparatus. Projectors are optimized to provide maximum luminous flux to a screen, with secondary emphasis placed on characteristics important in printing, such as contrast and resolution. Optical systems for projector and display applications are designed for the response of the human eye, which, when viewing a display, is relatively insensitive to image artifacts and aberrations and to image non-uniformity, since the displayed image is continually refreshed and is viewed from a distance. However, when viewing printed output from a high-resolution printing system, the human eye is not nearly as "forgiving"

to artifacts and aberrations and to non-uniformity, since irregularities in optical response are more readily visible and objectionable on printed output. For this reason, there can be considerable complexity in optical systems for providing a uniform exposure energy for printing. Even more significant are differences in resolution requirements. Adapted for the human eye, projection and display systems are optimized for viewing at relatively low resolutions such as 72 dpi or less, for example. Photographic printing apparatus, on the other hand, must achieve much higher resolution, particularly with apparatus designed for micrographics applications, which can be expected to provide 8,000 dpi for some systems.

Referring to Figure 1a, there is shown, in simplified form, the basic arrangement of an exemplary prior art imaging apparatus 10 configured as a color printer with separate red, green, and blue (RGB) color channels. There are similar components for modulating each color, represented in Figure 1a with appended color designators when necessary: r for red, g for green, and b for blue color. A photosensitive medium 32, fed from a reel 34 onto the image plane shown as a surface 36 has characteristic cyan, magenta, and yellow response corresponding to the modulated R, G, B colored light. For the red color light modulation path, a light source 20r provides red light. Uniformizing optics 22r perform basic functions that collect light and provide uniform light for modulation. A polarization beamsplitter 24r directs unmodulated light of a given polarity to a spatial light modulator 30r. The uniformized light from light source 20r is modulated by spatial light modulator 30r, is transmitted through polarization beamsplitter 24r, and is combined at a color combiner, dichroic x-cube 26, with modulated light from corresponding components in the green light path (20g, 22g, 24g, 30g) and blue light path (20b, 22b, 24b, 30b). The modulated color image is then directed by a lens 38 for printing at surface 36. As indicated for the green color channel, the image-forming surface of each spatial light modulator 30 is positionally located at a fixed imaging plane P with respect to the imaging optics.

It must be observed that the arrangement of Figure 1a represents a limited number of the possible embodiments for imaging apparatus 10 using area spatial light modulators 30. For example, simpler systems can be built using a

single spatial light modulator 30 that is shared or multiplexed between two or three light paths, such as that shown in Figure 1b. In this configuration, a light source 20 provides an illumination beam of red, green, and blue light in a sequence, by means of a filter wheel 28 driven by a motor 18, as is well known in the imaging art. Other methods for directing, as an illumination beam, one color at a time include using separate LEDs having the appropriate color, for example. Uniformizing optics 22 homogenize the illumination beam and provide a uniform field to a polarizing device, such as a polarization beamsplitter 24. Light of suitable polarity for modulation is then directed to a spatial light modulator 30, which modulates the illumination beam with image data that corresponds to the color of the illumination beam provided. For this method, the sequencing of image data corresponds to the sequencing of color in the illumination beam. The modulated color image is then directed by lens 38 for printing at surface 36. Again, the image-forming surface of spatial light modulator 30 is positionally located at an imaging plane P with respect to lens 38 and other imaging optics.

A number of modifications is possible for the configurations of Figures 1a and 1b, using techniques well known in the imaging arts. For example, one or more transmissive LCDs could be used instead of the reflective LCDs shown as spatial light modulators 30, 30r, 30g, and 30b, with a suitable rearrangement of support components in each color path.

Referring to Figure 2, there is shown the arrangement of an ideal imaged pixel array 130 that would be provided by spatial light modulator 30. Pixel array 130 comprises individual pixels 72 arranged in a two-dimensional matrix having evenly spaced rows and columns as shown. A pixel-to-pixel distance D is a factor of the inherent spatial light modulator resolution, and is measured from the center of one pixel 72 to the center of an adjacent pixel 72. As a coarse approximation of the range of displacement distances, a pixel-to-pixel distance D for a typical LCD area spatial light modulator is typically from 10 to 12 microns.

Dithering is one method used for improving the imaging characteristics of pixel array 130. Referring to Figure 3, there is shown a conventional dithering pattern that has been proposed for compensating for low

fill factor of pixels 72 or for increasing pixel resolution. Dither movement of spatial light modulator 30 (Figures 1a and 1b) or of some other component in the optics path for modulated light effectively shifts pixels 72 from an original imaging position 78a to a second imaging position 78b, then to a third imaging position 78c, and then to a fourth imaging position 78d. This repeated pattern minimizes the space between pixels to improve pixel fill factor, reducing "pixelization" effects, and increases apparent resolution, as is shown in the dithered pixel array 130 representation of Figure 4. The image data provided to the spatial light modulator is preferably changed with each shift operation, to effectively provide increased resolution. Conventionally, displacement needed for dithering is a fraction of a pixel; however, multiple-pixel dithering is also possible. Commonly-assigned U.S. Patent Nos. 6,552,740 and 6,547,032 disclose various dithering approaches for imaging apparatus employing area spatial light modulators.

The same type of technique, using controlled incremental motion as shown in Figure 3, can be used for increasing the effective resolution of an image sensor, such as a CCD array, for example. In the imaging arts, the term "dithering" has been used primarily in a printing context. However, for the purposes of this disclosure, this term is used with broader application, to describe the type of pixel displacement described with reference to Figure 3 for both image-sensing and image-forming devices. For any of these devices, as was described with reference to Figures 1a and 1b, dithering provides movement that is substantially within the fixed plane P of the surface of spatial light modulator 30. As shown in the conventional coordinate axis representation of Figure 3, dithering typically provides displacement in the directions of mutually orthogonal x and y axes, which lie within plane P in the context of Figures 1a and 1b. There is, however, no appreciable displacement in the direction of the z axis, that is, in the direction of incident light, chiefly in order to maintain correct focus. Moreover, any dithering mechanism must also constrain any rotational displacement about the z axis (referred to as θ_z).

Various mechanisms for providing controlled dithering motion and thereby increasing effective image resolution have been proposed, with application to various fields, including the following:

Commonly-assigned U.S. Patent No. 5,400,070 discloses an imaging sensing apparatus using a tiltable refraction plate for redirecting incoming light to a solid state image sensor, such as a charge-coupled device (CCD), where a motor-actuated cam is used to provide suitable tilting action;

U.S. Patent No. 5,786,901 discloses an image shifting device using piezoelectric actuators to control the tilt of a refraction plate in the optical path of an image sensor;

U.S. Patent No. 5,557,327 discloses a mechanism for pixel shifting within an image sensing apparatus using motors cooperating with spring constraints to tilt a refractive element to one or more positions;

U.S. Patent No. 4,449,213 discloses an optical reading apparatus providing X-Y displacement using electromagnetic actuation to shift the position of an objective lens;

U.S. Patent No. 4,581,649 discloses a system for improved image detection using dithering motion caused by solenoid actuation;

U.S. Patent No. 4,607,287 discloses vibration of an image sensor using piezoelectric actuators to achieve higher image resolution;

Commonly-assigned U.S. Patent No. 5,063,450 discloses a dithering motion in a camera for prevention of aliasing, wherein an image sensor is mounted onto a piezoelectric actuator;

U.S. Patent No. 4,633,317 discloses an electro-optical detector system using a dithered image offset controlled using electromagnetic actuators driving a reflective member; and

U.S. Patent Application Publication No. 2003/0063838 discloses a beam steering apparatus using piezoelectric actuators for cross-connect switching of optical signals.

As the above listing shows, mechanisms employed for providing the displacement needed for dithering have included electromagnetic and piezoelectric actuators. These devices can achieve precision movement over various ranges, depending on the device type. However, while each of the above-mentioned approaches has merit for a particular application, given a specific displacement distance, prior art approaches have not provided a low-cost, precision dithering mechanism that can, at the same time, be adapted for a range of different displacement distances and meets rigid criteria for compactness, robustness, and adjustability. Moreover, there are advantages to solutions that do not interpose added optical components, such as glass plates, which can be sensitive to dirt and dust and may introduce unwanted optical effects.

Thus, it can be seen that there is a need for an apparatus and method for achieving controlled dither motion of an imaging device in orthogonal directions, within a fixed plane.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a dither mechanism for precision pixel displacement within an imaging apparatus. With this object in mind, the present invention provides an apparatus for shifting a movable platen between a resting position and an actuated position, the apparatus comprising:

(a) means for suspending the movable platen from a stationary housing to allow movement of the movable platen between the resting and actuated positions;

(b) a lever member pivoted at a flexure element, the flexure element being coupled to the stationary housing, the position of the flexure element along the lever member defining:

(i) a working arm of the lever member between the flexure element and the movable platen;

(ii) an effort arm of the lever member between the flexure element and the point of contact of an actuator; and

the effort arm driven by the actuator to shift the movable platen from the resting position to the actuated position, such that the travel distance of the movable platen between the resting position and the actuated position is proportional to the ratio of the length of the working arm to the length of the effort arm.

From another aspect, the present invention provides an apparatus for displacing a movable platen in first and second directions, substantially within the fixed plane of the surface of the platen, the apparatus comprising:

(a) means for suspending the movable platen from a stationary housing to allow movement within the fixed plane;

(b) a first actuator for providing a first displacement along the first direction and a second actuator for providing a second displacement along the second direction;

(c) a lever member pivoted at a flexure element, the flexure element being coupled to the stationary housing, the position of the flexure element along the lever member defining:

(i) a working arm of the lever member between the flexure element and the movable platen;

(ii) an effort arm of the lever member between the flexure element and the point of contact of the first actuator; and

the effort arm driven by the first actuator and by the second actuator, such that the travel distance of the movable platen relative to the first displacement of the first actuator is proportional to the ratio of the length of the working arm to the length of the effort arm.

It is a feature of the present invention that it employs levered motion for multiplying the displacement provided by an actuator by a predetermined ratio.

It is an advantage of the present invention that it provides a low-cost apparatus for achieving precision dithering displacement. The apparatus of

the present invention provides this controlled movement within the fixed plane of the surface of an image-forming or image-sensing device, so that dithering can be achieved without a refocus requirement. At the same time, the apparatus and method of the present invention prevent undesirable rotation of the image-forming or image-sensing surface.

It is a further advantage of the present invention that it does not introduce additional components into the optical path for the purpose of providing dither displacement.

It is yet a further advantage of the present invention that it enables compact packaging of components for achieving precision dither displacement.

It is yet a further advantage of the present invention that it provides a low-cost mechanism for dithering that is robust and can be used for both image-forming and image-sensing devices.

These and other objects, features, and advantages of the present invention will become apparent to those skilled in the art upon a reading of the following detailed description when taken in conjunction with the drawings wherein there is shown and described an illustrative embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter of the present invention, it is believed that the invention will be better understood from the following description when taken in conjunction with the accompanying drawings, wherein:

Figure 1a is a schematic block diagram showing an image-forming apparatus using an area spatial light modulator in each of three color paths;

Figure 1b is a schematic block diagram showing an image-forming apparatus using an area spatial light modulator for each color component of an image;

Figure 2 is a plan view showing a basic pixel arrangement for a representative portion of an area spatial light modulator;

Figure 3 shows a dithering sequence conventionally used for increasing effective resolution and for improving pixel fill factor;

Figure 4 shows an example image resulting from conventional dithering;

Figure 5 is a perspective view showing suspension of a holder for an imaging device;

Figure 6 is an enlarged, cutaway side view showing connection of a wire flexure for suspension of the holder in Figure 5;

Figure 7 is a plane view showing a torsion-constraining sheet flexure used for controlling movement in the apparatus of the present invention;

Figure 8 is a perspective view showing a portion of the components used for controlling movement in the apparatus of the present invention;

Figure 9 is a perspective view adding a housing used for mounting components in the apparatus of the present invention; and

Figure 10 is a perspective view showing an assembled apparatus for controlling movement according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present description is directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

Figures 5, 6, and 7 show various components and techniques used for key mechanical elements of a preferred embodiment device. Referring to Figure 5, there is shown a perspective rear view of a platen 50 for allowing movement between a resting position and an actuated position, in a single direction or in orthogonal directions x and y within the same fixed plane. Platen 50 is suspended from a mounting element, described subsequently, using clamped wire flexures 52. Wire flexures 52 allow only the slight displacement of platen 50 needed for dithering, with only minimal movement along the z direction, so that the movement of platen 50 can be considered to be substantially within a fixed plane. The dither apparatus of the present invention mounts, to the front side of a mounting surface 42 of platen 50 (not visible in the view of Figure 5), spatial light modulator 30 (shown in dotted outline). In one embodiment, wire flexures 52 are .010 stainless steel, having sufficient strength for maintaining platen 50 in either

resting or actuated positions. Figure 6 shows, for one embodiment, how wire flexure 52 is attached orthogonally to platen 50, using a V-feature 60 for seating wire flexure 52, with a clamp 54 fastened using screw 56 to a support member 44. Clamp 54 is thereby held tightly against wire flexure 52.

Referring to Figure 7, there is shown a sheet flexure 62 used to provide mechanical coupling with torsional constraint in an apparatus of the present invention. Sheet flexure 62 comprises an annular portion 64 around an opening 68 and an arrangement of tangentially extended arms 66. Each extended arm 66 can be mechanically mounted using holes 74. With this arrangement, sheet flexure 62 allows a slight degree of bending for movement of an element that is seated within opening 68, without allowing rotation relative within the plane of extended arms 66.

Referring to Figure 8, there is shown a partial assembly of the overall mechanism that provides controlled displacement to platen 50 in orthogonal directions. Actuators 40 provide linear force against an effort arm 76 of a lever member 70 in the x or y direction, as shown. Lever member 70 is fitted within sheet flexure 62, thereby establishing a pivot point P that, in turn, defines length L1 of effort arm 76 and length L2 of a resistance arm or working arm 58. Applying standard lever principles, it can be seen that lever action multiplies the incremental movement of actuator 40 by the ratio of lengths L2:L1. This multiplier causes a displacement of platen 50 according to actuator 40 direction. Lever member 70 is mounted to platen 50 using another sheet flexure 62. This arrangement effectively provides a fulcrum and constrains rotational movement of platen 50 relative to lever member 70.

Referring to Figure 9, there is shown a more complete assembly that adds, to the basic arrangement shown in Figure 8, supporting mounting components for providing controlled displacement to platen 50. A housing 80 provides support for mounting sheet flexure 62 at pivot point P. Housing 80 also provides mounting support for suspension of platen 50, using wire flexures 52 as was described with reference to Figures 5 and 6. A bracket portion 82 of housing 80 provides screws 56 for attachment of wire flexures 52, as was shown in Figure 6. A small gap G is maintained between bracket portion 82 and platen 50,

allowing displacement of platen 50 by the action of lever member 70. To maintain gap G to a fixed distance value, an optional spring (not shown) can be fitted into gap G. A curved metal spring positioned within gap G, for example, would maintain gap G spacing as well as providing some friction damping constraint to improve settle time of platen 50 following movement between resting and actuated positions.

Referring to Figure 10, there is shown an added actuator support bracket 84 that is attached to housing 80 for mounting actuators 40. An adjustment screw 86 provides an adjustment for the position of actuator 40 in the x direction. Another adjustment screw 88 provides the corresponding function in the y direction. A flat spring 90 is fitted into actuator support bracket 84 to provide opposing force for movement of effort arm 76 of lever member 70.

<u>Leverage Options</u>

The apparatus of the present invention provides a robust mechanism for pixel dithering that meets demanding criteria for providing accurate movement in orthogonal x and y directions within a fixed plane. By specifying length L1 of effort arm 76 relative to length L2 of working arm 58, this apparatus provides a multiplier for the linear displacement of actuator 40, allowing movement to be accurately controlled to within tight tolerances. Where length $L2 > L1$, the highly accurate motion of a piezoelectric actuator can be harnessed and adapted for use well outside its conventional range of applications. Where length $L2 < L1$, scaled-down distances can be achieved more easily, thereby extending the usable range of many types of electromagnetic actuators for highly accurate positioning.

It must also be emphasized that the embodiment shown in Figures 8-10 employs a first class lever principle, where actuator 40 displacement of effort arm 76 in one direction causes corresponding displacement of working arm 58 and platen 50 in the opposite direction. Sheet flexure 62 defines the fulcrum position. Other types of lever arrangement are also possible for dithering motion, or other positioning motion, using the methods and apparatus of the present invention. Possible alternative arrangements include use of lever member 70 as a second class lever, with actuator 40 displacement in the same direction as platen 50 load

movement. For this type of arrangement, platen 50 would be between the fulcrum position defined by sheet flexure 62 and the point of application of actuator 40 force. Lever member 70 could also be deployed as a third class lever, where effort arm 76 displacement is also in the same direction as platen 50 is moved. In a third class lever configuration, actuator 40 force would be applied between the fulcrum, defined by the position of sheet flexure 62, and platen 50.

Unlike the first class configuration in which working arm 58 and effort arm 76 are on opposite sides of the fulcrum point defined by sheet flexure 62, working arm 58 and effort arm 76 overlap in second and third class lever arrangements. In each case, however, the distance of working arm 58 (L2 for the first class lever arrangement of the embodiment in Figure 8) is the distance between the fulcrum (sheet flexure 62) and the load (platen 50). Effort arm 76 (L1 for the first class lever arrangement of the embodiment in Figure 8) has a distance measured between the fulcrum (sheet flexure 62) and the point of force applied by actuator 40.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention as described above, and as noted in the appended claims, by a person of ordinary skill in the art without departing from the scope of the invention. As is emphasized hereinabove, the apparatus and method of the present invention could be applied to a broad range of imaging devices, including both image-forming devices and image-sensing devices, such as those using charge-coupled devices (CCDs) as sensors. The apparatus and method described could alternately be applied to devices other than those used for imaging, such as for highly accurate positioning of components. Actuator 40, a piezoelectric device in the embodiment described, could be another type, such as an electromagnetic actuator. While actuators 40 apply force at mutually orthogonal angles in the preferred embodiment of Figures 8-10, other arrangements are possible, provided platen 50 is constrained from movement along or rotation about the z-axis. The function of housing 80 could be implemented in a number of alternate ways, suited to the configuration of the overall apparatus.

The apparatus of the present invention provides a limited range of motion of platen 50 in orthogonal x and y directions within a fixed plane, effectively preventing movement in the z direction as well as preventing rotation about the z axis where z is in the direction of a normal to the surface of platen 50 as shown in Figure 8. In imaging apparatus, this requirement to constrain the position of platen 50 substantially within the same fixed plane relates to optical requirements. That is, the optical support system in an imaging apparatus typically allows only a minimal tolerance for movement in the z direction. Absolute constraint in the z direction is neither practical, nor required in most imaging apparatus that use dithering; however, any movement in the z direction must be minimized so that acceptable focus is maintained during dither movement.

As described hereinabove, the apparatus of the present invention operates in two orthogonal directions, enabling the convention dithering pattern of Figure 3 to be obtained. However, there may be applications for controlled precision displacement between a resting position and an actuated position in only a single direction using the apparatus and method of the present invention. For example, using a single actuator 40, movable platen 50 could be used to support a linear spatial light modulator, or to mount an area spatial light modulator 30 for dither motion in a single direction only.

Thus, what is provided is an apparatus and method for providing precision movement that is particularly well adapted to imaging applications for image-sensing or image-forming apparatus.

PARTS LIST

10	imaging apparatus
18	motor
20	light source
20r	light source, red
20g	light source, green
20b	light source, blue
22	uniformizing optics
22r	uniformizing optics, red
22g	uniformizing optics, green
22b	uniformizing optics, blue
24	polarization beamsplitter
24r	polarization beamsplitter, red
24g	polarization beamsplitter, green
24b	polarization beamsplitter, blue
26	x-cube
28	filter wheel
30	spatial light modulator
30r	spatial light modulator, red
30g	spatial light modulator, green
30b	spatial light modulator, blue
32	photosensitive medium
34	reel
36	surface
38	lens
40	actuator
42	mounting surface
44	support member
50	platen
52	wire flexures
54	clamp
56	screw

58	working arm
60	V-feature
62	sheet flexure
64	annular portion
66	extended arm
68	opening
70	lever member
72	pixel
74	holes
76	effort arm
78a	original imaging position
78b	second imaging position
78c	third imaging position
78d	fourth imaging position
80	housing
82	bracket portion
84	actuator support bracket
86	adjustment screw
88	adjustment screw
90	spring
130	pixel array